Photosynthesis Under Field Conditions. XB. Origins of Short-Time CO_2 Fluctuations in a Cornfield[1]

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ABSTRACT

Studies of the vertical distributions of CO_2 fluctuation in a cornfield were made in the 4-to 0.25-cycle/min frequency range. Amplitude of fluctuations decreased with height above the ground. Frequency in this range appeared rather constant, however. Sources and sinks for CO_2 within the cornfield contribute to the fluctuations; however, eddy structure originating inside and/or outside the cornfield plays an important role too.

Additional key words: Atmospheric CO_2 fluctuation, 4-to 0.25-cycle/min frequency, Cornfield, CO_2 sources and sinks, Eddy structure.

IT has long been known that the CO_2 content of the air near the earth's surface undergoes temporal and spatial fluctuations arising from inhomogeneous distribution of sources and sinks of carbon dioxide as well as the degree of air mixing by meteorological processes (Huber, 1952). The fluctuations can present serious problems when sampling to obtain representative values of the carbon dioxide content of the air. We have found this especially true in our studies of CO_2 exchange above active plant communities.

We have been well aware of the shorter time fluctuations of $\frac{1}{4}$ to 2 cycles per minute, and as a consequence have attempted to obtain integrated samples for 10- to 20-min sampling periods. However, previously no attempts were made to study the short-time fluctuations themselves. This paper will discuss such a study in a field of full-grown corn (Zea mays L.).

Although the site has been described previously (Lemon et al., 1963), certain features of the location are pertinent to this study. The corn was relatively isolated as a frost-sensitive crop in an area of mixed vegetation of frost-hardy species. Also, the wind fetch over the corn to the sampling site was approximately 100 m. The significance of these two points will be discussed later.

SAMPLING PROCEDURE FOR CO_2

Two procedures for sampling CO_2 were followed: (1) During all but one of the six sampling periods, time- and space-integrated samples were collected and analyzed to provide mean

vertical profiles of CO_2 concentration above and within the crop. The procedure has been reported in detail in an accompanying paper (Lemon and Wright, 1969). In the present study, mean profile samples were taken at 380, 225, 135, 95, and 35 cm above the ground. The profiles, which are identified by time (EST), are presented in the left side of Fig. 1. (2) Concurrent with the collection of samples for a given mean profile, a continuous record of the fluctuating carbon dioxide content of the air at a single point above the ground was obtained. There were six "runs" of about 10-min duration each, with the continuous "fluctuation" samples taken in turn at the following levels above the ground: 520, 424, 305, 216, 140, and 51 cm. The corn was 285 cm tall with the uppermost large leaves at about 225 cm. Thus three fluctuation samples were taken above and three within the canopy. The results are presented on the right side of Fig. 1 as fluctuations from the mean for a given level of a specified mean profile. Each fluctuation sample is identified by height above the ground and time (EST) in association with a particular mean vertical profile. Graphed points of the fluctuation samples are instantaneous values from continuous chart recordings.

Further details of the continuously recorded samplings are presented. A single 50-m length of 0.5 cm ID tygon tubing was attached to the suction side of an aquarium pump to provide sample air direct to an infrared CO_2 gas analyzer. The inlet of the tubing was supported on a mast in the corn upwind from the instrument trailer, and was sequentially positioned on the mast at the given sampling levels beginning at the top. The tubing from the mast to the trailer was strung on corn leaves through the crop at about 150 cm above the ground. This minimized possible diffusion of CO_2 into the tubing from the higher concentrations of CO_2 near the ground. Also higher daytime temperatures near the ground induce evolution of organic gases out of the tubing, causing additive errors in measurement by infrared methods. Both if these errors were minimized by a high air sampling rate. Since emphasis here is on short-time fluctuations, such errors are likely to be of no significance. The disappearance of the fluctuations after the corn was killed by a frost indicated that the fluctuations were indeed caused by conditions external to the sampling system.

The aquarium pump delivered air at a constant 2.5 liters/min. The exhaust side of the pump led directly into a special carbon dioxide infrared analyzer having a range of $\pm$ 12.5 ppm with a sensitivity of $\pm$ 0.2 ppm. Other details of the instrument are reported elsewhere (Wright and Lemon, 1966).

Prior to each run the sampling airstream was split into two streams before entering the analyzer, one going through the "sample cell" and the other through the "reference cell." Both were exhausted to ambient atmospheric pressure. In this way "zero" differential was established, with air of like composition in each cell (i.e. both in CO_2 and water vapor). At the start of a run the "reference cell" was closed and the sample air continuously put through the "sample cell" only. Thus, the continuous fluctuations were relative to the air composition at the beginning of a run. The analyzer had sufficient discrimination between water vapor and carbon dioxide so that when used in this way it was not necessary to remove the water vapor.

Before the study was begun it was important to determine the system response time. The problem of sample "smearing" during flow through the long sampling tubing could be a serious complication. This problem was investigated by passing "square-wave" differentials of CO_2 concentration through the sampling tubes. Fig. 2 presents the results of two such studies on the tubing used in these studies (Lemon and Wright, 1969). The

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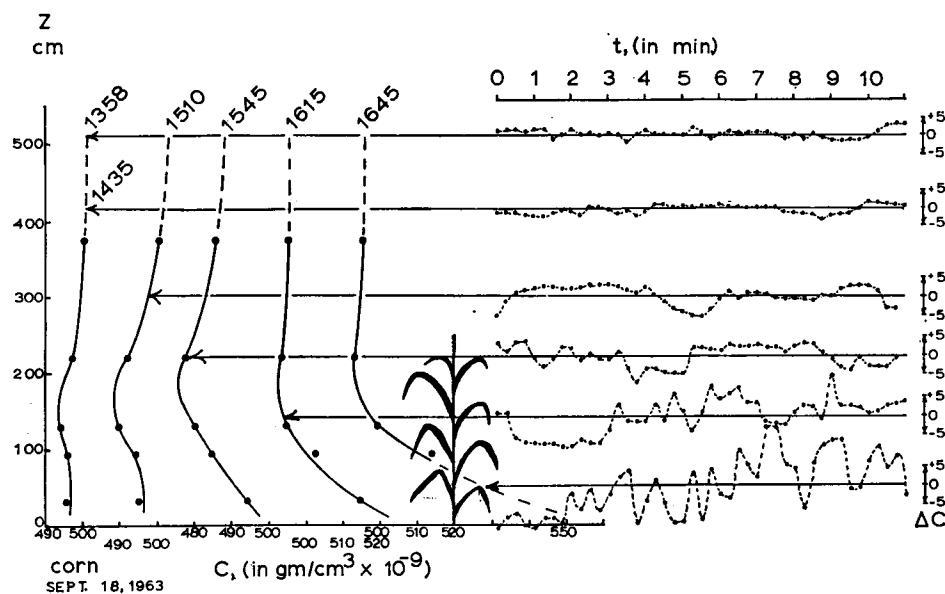
Fig. 1. Mean CO_2 concentration (C) profiles in a cornfield for the indicated time (EST) and the variation (Δc) from the mean during the 10-min sampling period for each specific time and level as indicated by arrow. Ellis Hollow, N. Y.

test procedure was this. Two tanks of standard gases differing in CO_2 concentration by 5.0 ± 0.2 ppm were connected to the differential CO_2 analyzer. Flow regulators and pressure regulators were used to assure equality of input to both "reference" and "sample" cells of the analyzer. Output was exhausted to ambient air. In all cases the input air was passed through magnesium perchlorate absorbers immediately before entering the analyzer cells. First, equal and short lengths of copper tubing to both cells were used to establish that differential carbon dioxide concentration was 5.0 ± 0.2 ppm without the long test tubing. The differentials were reversed by switching input standard gases at the tank outlets. This served to check zero and span characteristics of the analyzer. Following this the test tubing was inserted in series to one cell of the analyzer, air flow and pressure regulated and equilibrium established. Not all the flow of air through the PVC garden hose was passed through the analyzer, however. A small subsample stream was bled into the analyzer at the rate of 1 liter/min. This subsample was passed through the drier tube before entering the analyzer.

Once the analyzer recorder indicated equilibrium of the system, the concentration differentials were reversed at the tank outlets and the system was allowed to come to equilibrium once again. A continuous chart recording of each cycle permitted several cycles to be clearly defined. Fig. 2 shows the elapsed time of representative cycles for the two tubings tested. It should be noted first that there appears to be no CO_2 contamination with the rapid airflow rates we use in our experiments. The differentials were 5.0 ± 0.2 ppm with and without the sample tubing. Apparently, too, the lag characteristics of the two types of tubing tested were similar with the different airflow rates used.

The shapes of the response curves need explanation. At time zero when concentration differentials have just been reversed there will be a period when the air entering both cells is alike in concentration due to the fact that there is a large "ballast" of air in the long sample tubing. Purging of the drier tubes and analyzer cells takes about 10 to 20 sec at a flow rate of 2.2 liters/min or 20 to 30 sec at a flow rate of 1 liter/min. At the end of this period there is a momentary or transient equilibrium of "no differential" air in the analyzer, producing the "step" in the tygon
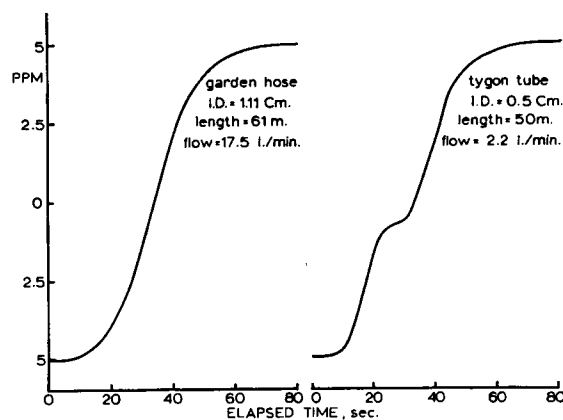

Fig. 2. CO_2 sampling plus analytical system response characteristics to a square wave input of CO_2 differential of 5 ppm in air.

curve. (Evidently the transition was so gradual in the PVC garden hose that no step is apparent.) We interpret the response in the tygon tubing to begin at 30 sec and to be 2/3 complete at 40 sec, with almost complete equilibrium in 60 sec. We also interpret from the same curve the analyzer response to be 2/3 complete in 15 sec with almost complete response in 20 sec. Thus as a conservative estimate, the complete system as used in this fluctuation study was capable of detecting fluctuations with a frequency of up to 4 cycles/min. Higher frequencies were filtered out by both lead in hoses and instrument response time. Interestingly enough, however, the fluctuations appearing in Fig. 1 are primarily of lower frequency, i.e., $\frac{1}{4}$ to 1 cycle/min.

As to the matter of the wind velocity in the cornfield during the study, we can only present mean velocities for the six sampling periods (Table 1). The methods of obtaining these results are discussed by Lemon and Wright (1969).

Table 1. Mean wind velocity at various levels above and within a canopy of corn. Ellis Hollow, N. Y. Sept. 18, 1963.

Time (EST)	Wind velocity (cm/sec) at various height above ground, cm					
	520	424	305	216	140	51
1358-1408	272	241	187	99	32	14
1435-1445	227	202	156	82	27	11
1510-1520	205	182	141	74	24	10
1545-1555	218	193	150	79	26	11
1615-1625	141	125	97	51	17	7
1645-1655	138	122	95	50	16	7

Height of corn was 285 cm. Underlined figures indicate mean velocities at time and height of CO_2 fluctuation sampling.

Table 1 indicates that general wind flow decreased gradually as the afternoon progressed. However, this decrease was minor compared to the decrease in wind as sampling height decreased. Thus in Fig. 1, the increase in amplitude of the CO_2 fluctuations as the ground is approached can be associated with a decrease in wind velocity caused primarily by canopy resistance.

Because of the scale of height of measurement and the filtering out of frequencies more rapid than 4 cycles/min, it is doubtful that any change in frequency of CO_2 fluctuation with height can or should be detected.

We are now at a point where it may be appropriate to discuss the origin of the observed low frequency fluctuations. When we first observed this phenomenon several years ago at the same site, we reasoned that the fluctuations were generated outside the field because the eddy scale was larger than the upwind fetch in the field. For example, at a low mean wind flow of 1 m/sec just above the canopy and a ½ cycle/min fluctuation, the eddy scale would be 120 m (1 meter /sec × 60 sec/min × ½). At a moderate wind of 2 or 3 m/sec, the eddy scale would be 240 to 360 m, considerably greater than our 100-m fetch in the cornfield.

However, two findings in this study have caused us to question our earlier reasoning: (1) Three days following the fluctuation study the corn was killed by a frost, causing a subsequent cessation of CO_2 fluctuation at all levels (surrounding frost-hardy vegetation appeared to be unharmed). (2) The frequency of fluctuation before frost, appeared to be independent of height despite the wide range of windspeeds during the day.

Therefore, we now propose that the CO_2 fluctuations are indeed generated in the cornfield by variable sources and sinks associated with photosynthesis and respiration. Furthermore, the eddies contributing to the fluctuations could be originating either inside or outside the field or both. In any case, they have to be moving across the field at a much slower velocity than the mean windspeed. Nothing can be inferred about their size or shape. We now need to make simultaneous fluctuation measurements at several horizontal and vertical points to throw additional light on this phenomenon. Further studies of this phenomenon also can lead to useful application in measuring CO_2 exchange in the field by a "direct" method (Inoue, 1964).

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